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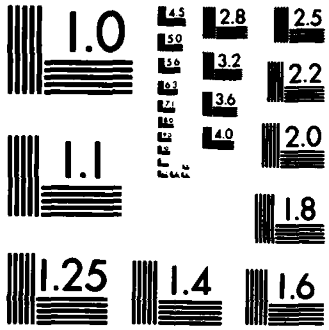

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Finite Element Analysis of Centrifuged Concrete Culverts

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The objective of this study was to develop an improved design tool to better predict the soil-structure interaction of underground protective structures using finite element analysis and centrifuge modeling technology. This study shows that the results obtained from an existing finite element computer code, CANDE, and actual centrifuge behavior is quite favorable. Two soil models, a linear model and Duncan's hyperbolic model, were used to show the influence of constitutive relationships on the overall response of the system.

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PREFACE

This report was prepared by the Air Force Engineering and Services Center, Engineering and Services Laboratory, Engineering Research Division at Tyndall Air Force Base, Florida under Job Order Number 26730025, Evaluate/Improve Structural Response Models. This effort was funded by the Air Force Office of Scientific Research under their 1984 USAF/SCEEE Summer Faculty Research Program.

The report covers work performed between 21 May and 29 July 1984. The AFESC/RDCS Project Officer was Capt Paul L. Rosengren, Jr.

This study shows that Finite Element analysis can be a useful tool in examining the validity of the results of centrifugal model testing as long as the constitutive relationships for soil are representative of actual behavior.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SECTION I
INTRODUCTION

A. PURPOSE

Soil-structure interaction problems have long been of interest and concern for geotechnical engineers. Although rapid progress has been made in solving these problems, their application to concrete culverts embedded in embankments has been slow. Due to an increased number of concrete culvert projects in industry, state highway departments, and federal agencies in the United States during recent years, research could improve the design/analysis of concrete culverts and result in better structural stability, and time and cost savings.

B. OBJECTIVES

One currently used design method for buried culverts, originally developed by Marston (Reference 1) early in the century, has been modified by Spangler (Reference 2) and Costes (Reference 3). According to this method, the design of buried culverts in a soil fill depends on two empirical factors, settlement ratio and load factor. However, primary shortcomings of this method are: (1) the settlement ratio is not known before the culvert is built; and (2) the designer must predict this parameter from a few past experimental observations or by engineering judgment. Therefore, there is a need for more rational design methods on a sounder theoretical basis.

Perhaps the most ideal approach for obtaining information for the development of new design methods is full-scale model testing. A full-scale model with the necessary instrumentation (i.e., soil stress meters, settlement gauges, and strain gauges, etc.) could give the best results for estimating prototype behavior of buried culverts.

Unfortunately, full-scale model testing has serious major drawbacks: mainly, cost and time of construction and operation. Because of these reasons, the centrifugal modeling technique is becoming a favorite testing method in geotechnical engineering. This technique offers a comparatively inexpensive and easy way of obtaining essentially

the same data as could be obtained from field tests. It also provides opportunities for studying the effect of individual parameters, and collecting more data than field tests usually yield.

However, at present, there is limited capability to add or remove soil in centrifugal flight. Thus a typical test of a model embankment involves subjecting that embankment to a gradually increasing centrifugal field, while maintaining it at its final shape. Although the models can be made large enough to include blocks of undisturbed and compacted soil which are representative of field conditions (References 4), an objection could be raised that the stress paths traversed by soil elements during the test are unrepresentative of those which apply in the field.

Therefore, this necessitates computational methods which examine the validity of such objections. Finite element techniques can be used to create mathematical models which model both the laboratory and the field situations, and allow the two to be compared. As long as constitutive equations for the soil used in the mathematical model are representative of real ones, valid comparisons should be possible.

Therefore, the objectives of the study are:

1. to investigate the influence of the constitutive equations for soil on the culvert response in finite element analysis, and
2. to compare the results of the finite element analysis to the results of the centrifugal model testing of the concrete culvert.

SECTION II

CENTRIFUGAL MODEL STUDY

The centrifugal model testing of the buried concrete culvert in sand was performed by James and Larsen (Reference 5) at Cambridge University, and only brief descriptions for the model testing procedures are summarized here.

A strong 17.8- by 15.2- by 5.9-inch rectangular box was mounted on the centrifuge. The box consisted of a frame made of hollow sections welded together, the frame was bolted to a back plate of mild steel and the front of the box was made of a Plexiglas® plate, which permitted observation of the model.

After mounting the strong box, the pipe, which was cast of microconcrete (i.e., concrete with scaled-down aggregates), was placed 1.2 inches away from the bottom of the box. The load cells were mounted in the pipe wall to measure the normal tractions, and strain gauges were glued on the inside and outside of the pipe wall to measure the bending moments and thrusts of the pipe. Sand was poured from a hopper into the box with approximately constant height of fall and rate of pouring. To reduce side friction in the box, glass plates were used between the sand and steel plate and between the sand and the Plexiglas® plate.

The speed of the centrifuge was then raised in steps of 5 g increments and the final load cell readings and strain gauge readings were taken at 35 g.

Figure 1 shows the geometry and boundary conditions of the model.

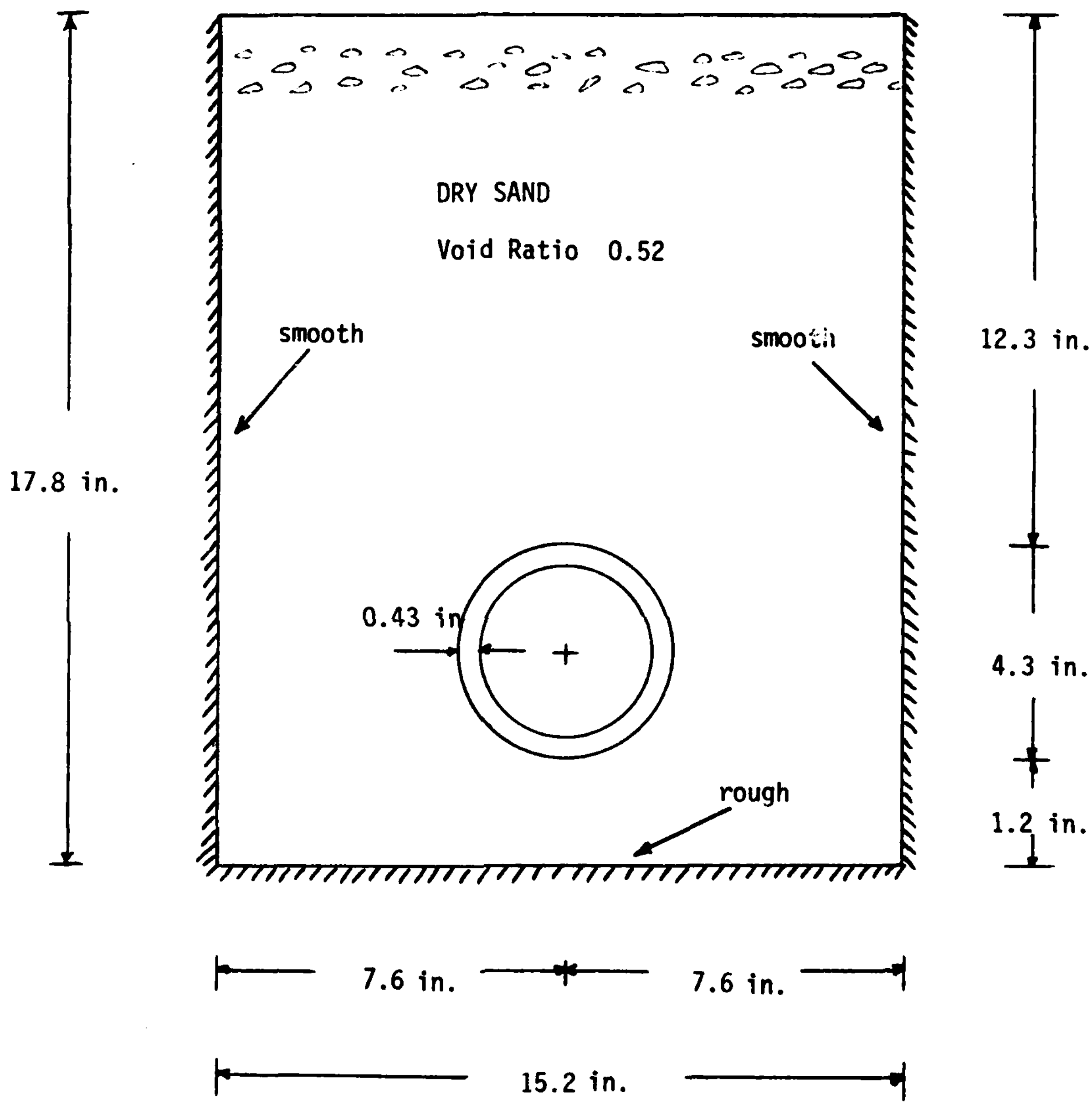

Figure 1. Geometry and Boundary Conditions

SECTION III
FINITE ELEMENT PROGRAM

The finite element program used in this study, CANDE (Culvert ANalysis and DEsign) was developed by Katona (References 6 and 7). Although CANDE can be operated in a design or analysis mode, only the analysis mode was utilized in this study. The main features of CANDE, which are used in the analysis, will be briefly described in this report.

The assumptions common to all solution levels in CANDE are: (1) Two-dimensional analysis with plane strain; and (2) small strain theory. There are three solution levels in CANDE. Level 1 corresponds to the elastic, closed solution while Levels 2 and 3 are both finite element (FE) solutions. The difference between Levels 2 and 3 is in the way the FE mesh is defined. Level 2 generates automatic and symmetric meshes for a circular, elliptical, or box culverts, whereas Level 3 allows the user to define a mesh. Since the model culvert used in this study was symmetric and circular, Level 2 was used.

Five material characterizations are available for various pipe materials in CANDE. These materials are: (1) steel; (2) aluminum; (3) plastic; and (4) concrete. In this study the concrete material characterization with a bilinear stress-strain relationship was used to represent the concrete material properties.

Three basic elements are contained in the program: a quadrilateral element for representation of the soil, an interface element for slip of elements, and a beam-column element for the culvert.

For representation of soil behavior, four types of constitutive relationships are incorporated with the program. These are: (1) linear elastic; (2) overburden-dependent; (3) extended Hardin's model; and (4) Duncan's hyperbolic model. To investigate the influence of the constitutive relationship for soil on the culvert response in the numerical analysis, both a linear elastic model and a nonlinear model (Duncan's hyperbolic model) for soil were used in the analyses. The results for each representation are presented in this report. In

Reference 5 only dense sand with a void ratio of 0.52 was specified, soil properties for the elastic (FE) soil model were assumed as: Young's modulus of 7,000 psi and Poisson's ratio of 0.3. A "SW" soil type at a compaction of level of 95 percent in Table 1 was used for Duncan's soil model. These values are within an expected range as recommended by Lambe (Reference 8) and Duncan (Reference 9), respectively.

The finite element grid with boundary conditions used in the comparison analysis is shown in Figure 2. The culvert was represented by 10 beam-column elements, the soil was represented by 86 quadrilateral elements, and the slip model was represented by 11 interface elements.

TABLE 1. REPRESENTATIVE PARAMETER VALUES OF THE MODIFIED DUNCAN MODEL (REFERENCE 9)

Unified Soil Classification	RC* Stand. AASHTO	γ_m k/ft³	ϕ_o deg	$\Delta\phi$ deg	c k/ft²	K	n	R_f	k_b	m
GW, GP SW, SP	105	0.150	42	9	0	600	0.4	0.7	175	0.2
	100	0.145	39	7	0	450	0.4	0.7	125	0.2
	95	0.140	36	5	0	300	0.4	0.7	75	0.2
	90	0.135	33	3	0	200	0.4	0.7	50	0.2
SM	100	0.135	36	8	0	600	0.25	0.7	450	0.0
	95	0.130	34	6	0	450	0.25	0.7	350	0.0
	90	0.125	32	4	0	300	0.25	0.7	250	0.0
	85	0.120	30	2	0	150	0.25	0.7	150	0.0
SM-SC	100	0.135	33	0	0.5	400	0.6	0.7	200	0.5
	95	0.130	33	0	0.4	200	0.6	0.7	100	0.5
	90	0.125	33	0	0.3	150	0.6	0.7	75	0.5
	85	0.120	33	0	0.2	100	0.6	0.7	50	0.5
CL	100	0.135	30	0	0.4	150	0.45	0.7	140	0.2
	95	0.130	30	0	0.3	120	0.45	0.7	110	0.2
	90	0.125	30	0	0.2	90	0.45	0.7	80	0.2
	85	0.120	30	0	0.1	60	0.45	0.7	50	0.2

* RC = relative compaction, in percent

Number of Nodes = 132
Number of Beam Elements = 10
Number of Quadrilateral Elements = 86
Number of Interface Elements = 11

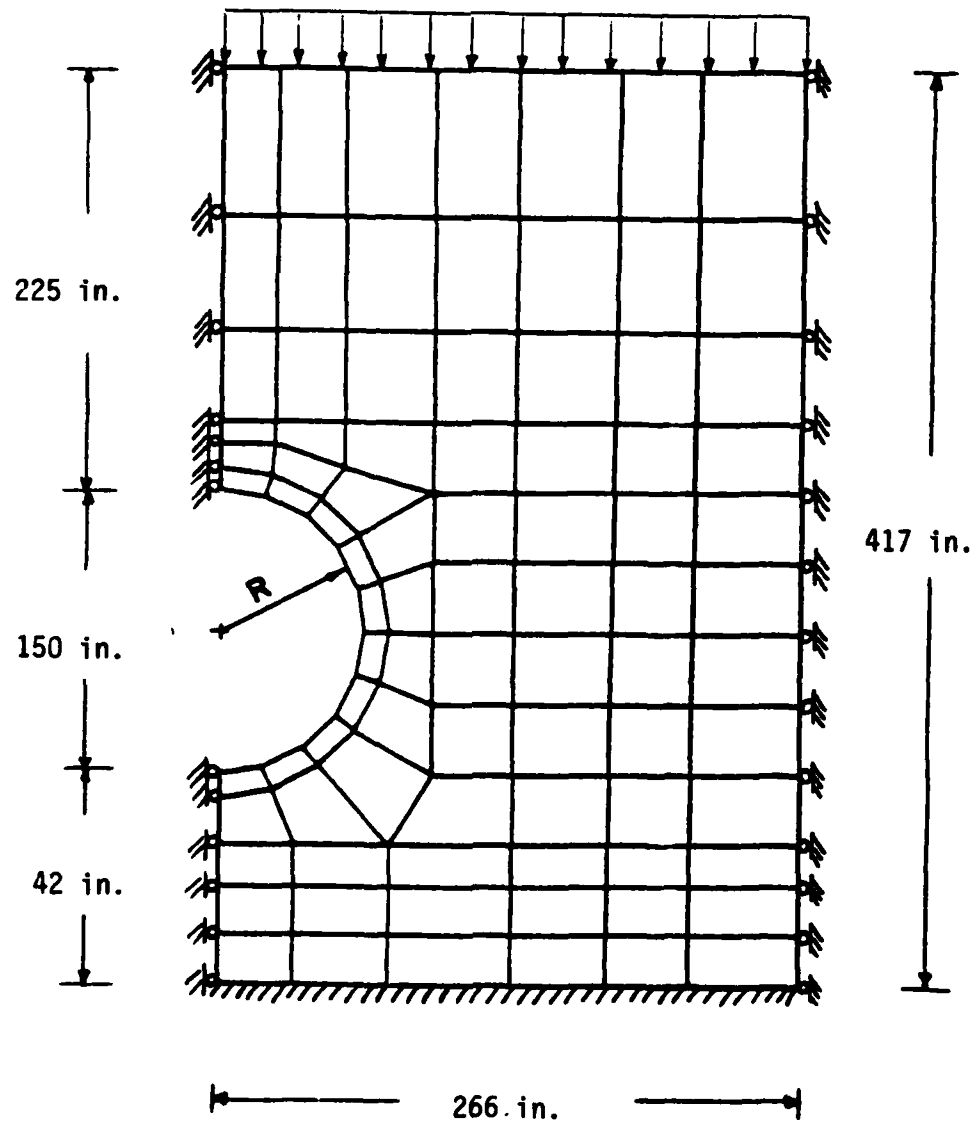

Figure 2. Symmetric Mesh

SECTION IV
RESULTS

The quasi-theoretical results obtained from the finite element code, CANDE, are compared to the results of the centrifugal testing model. The compared quantities are: (1) normal traction on the culvert periphery; (2) peripheral distribution of bending moment; and (3) peripheral distribution of thrust.

Figure 3 shows graphical comparisons between finite element results and centrifugal model testing observations for normal tractions acting at the culvert periphery. Excellent comparisons are observed from the results of numerical predictions with Duncan's soil model and the results of the centrifugal model testing. Trends of shape changes are similar and the magnitudes are in excellent agreement. In particular, the magnitudes around the positions of 30°, 90° (springing line), 144°, and 162 from the crown are almost identical to each other.

Yet, discrepancies exist between the numerical predictions with the linear soil model and other results obtained from the centrifugal testing model and numerical predictions with nonlinear soil model - even though the trend of shape change is similar.

Figure 4 shows internal, peripheral bending moment distributions of the culvert. As shown in from the figure, moderately good comparisons are observed between the results of numerical analyses and the results of the centrifugal testing model. Shape changes are similar and the magnitudes are in good agreement except around the invert. Positive moment in the figure is that which produces tension at the inner fibers of the concrete.

Figure 5 compares the results of finite element analyses and the centrifugal model study of circumferential thrusts of the culvert. Numerical predictions and model measurements are similar in shape, but do not agree well in magnitudes around the crown. Correlations are very good around the springing line and the invert.

Again, the results of CANDE with an elastic soil model are somewhat conservative when compared to other results.

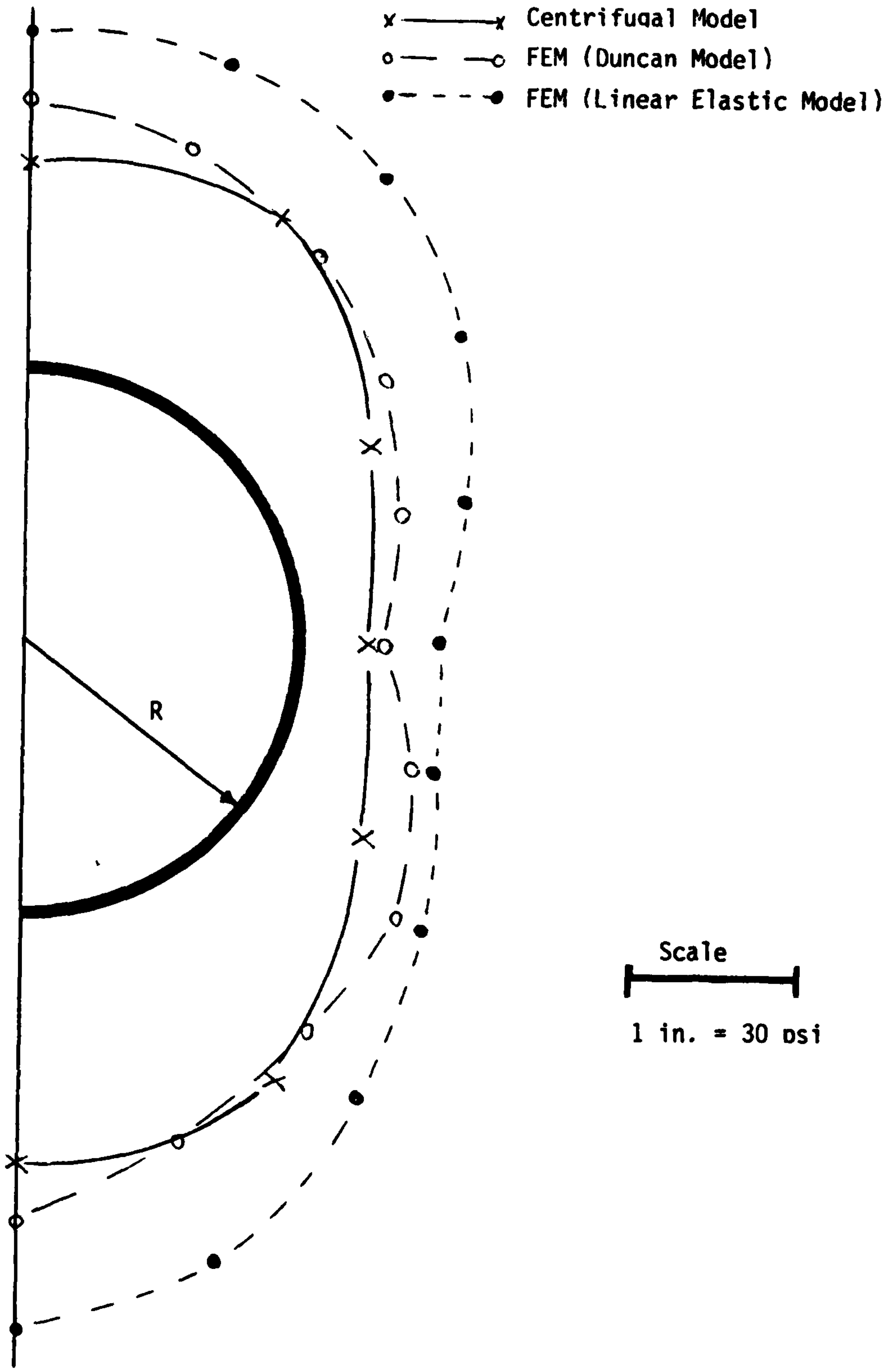

Figure 3. Normal Tractions on the Culvert Periphery

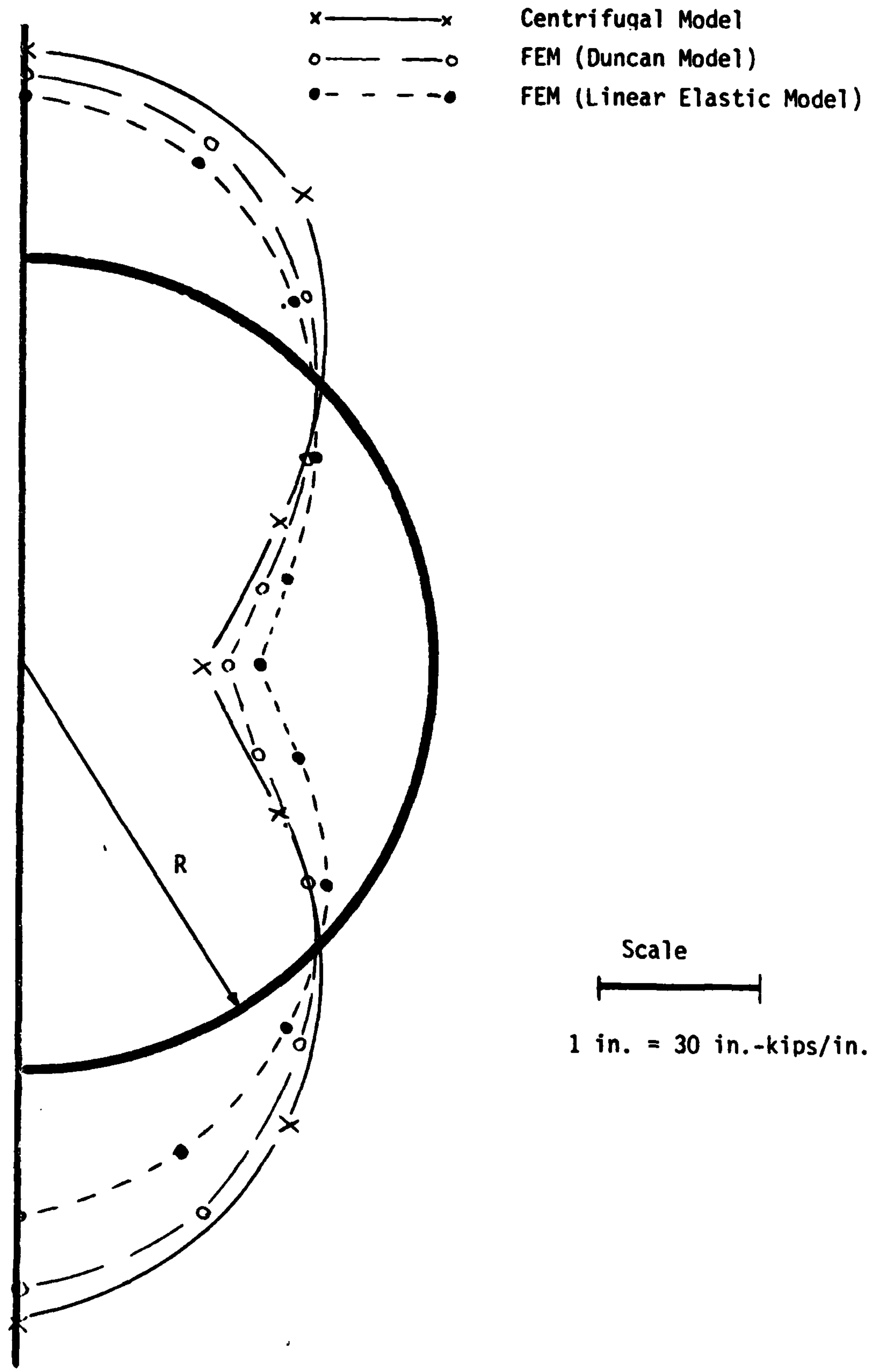

Figure 4. Peripheral Distribution of Bending Moment

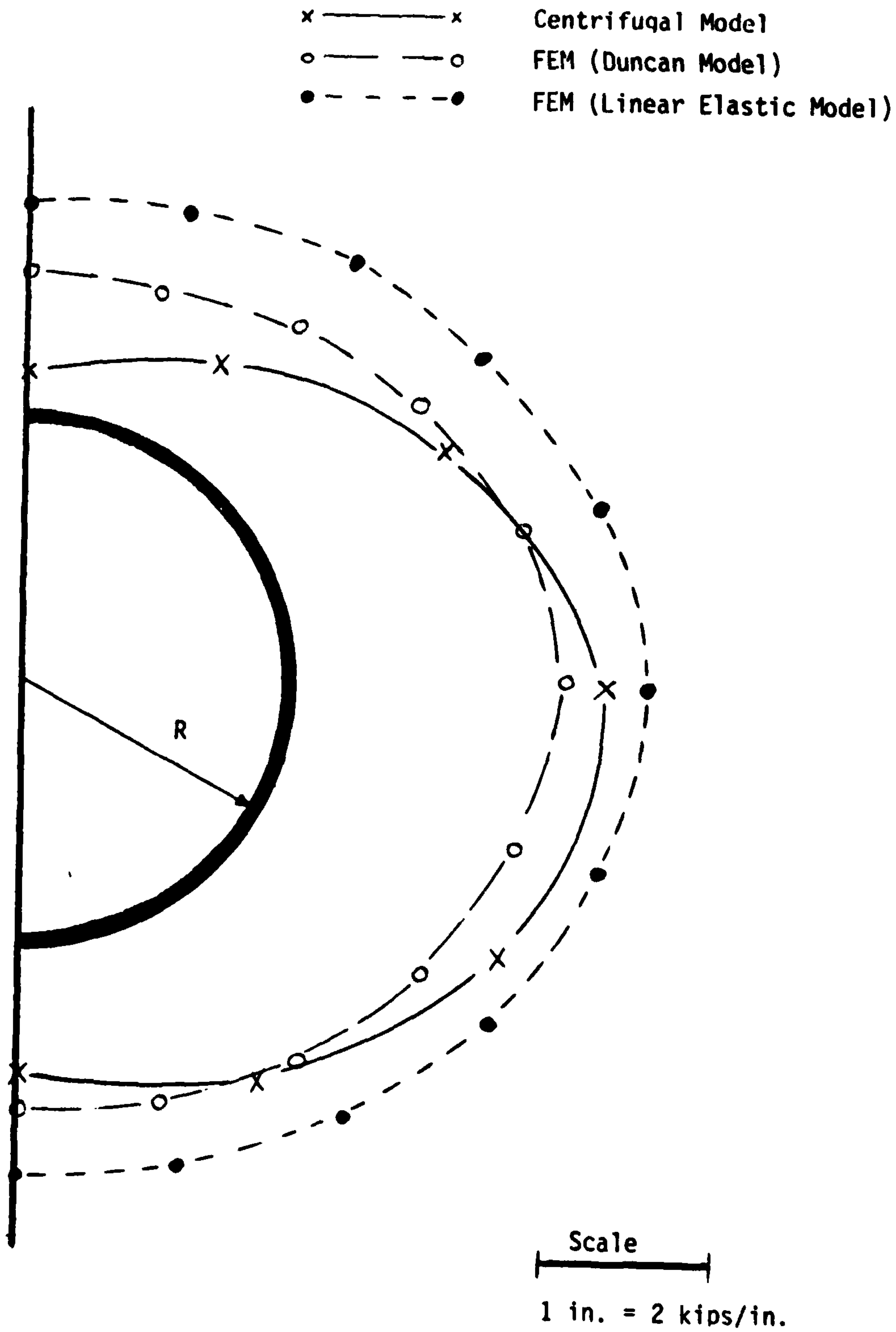

Figure 5. Peripheral Distribution of Thrust

SECTION V
RECOMMENDATIONS

This study evaluates the capabilities of a finite element method for analyzing the performance of buried structures by comparing the predicted and measured behavior of a concrete culvert. The findings and recommendations for further research based on this study are as follows:

1. The results of the finite element analyses compared well in shape with the results of the centrifugal testing model. Analysis with Duncan's hyperbolic relationships for soil exhibits a more realistic approach for predicting soil and culvert responses; the results were much closer to the results of the centrifugal testing model in shapes and magnitudes.
2. Significant economic savings (time and costs of construction and operations) could be obtained by using the centrifugal modeling technique to study the behavior of prototype buried culverts if results of the centrifuge model testing agree well with field measurements.
3. Additional economic savings could be obtained when numerical (finite element) analyses are used with realistic constitutive models for soils and culverts.
4. Additional studies (i.e., box, arch, or elliptical culverts with different bedding and boundary conditions) should be conducted for further verifications before general acceptance can be awarded.

REFERENCES

1. Marston, A., and Anderson, A.O., "The Theory of Loads on Pipes and Ditches," Bulletin 31, Iowa Engineering Experimental Station, Ames, Iowa, 1913.

2. Spangler, M.G., "Underground Conduits: An Appraisal of Modern Research," Transactions, ASCE, Vol. 113, June, 1947, pp. 316-374.

3. Costes, N.C., and Proudley, C.E., "Performance Study of Corrugated-Metal-Pipe Culvert Under Embankment-North Carolina," Flexible Culverts Under High Fills: Highway Research Board Bulletin 125, National Academy of Science, Washington, D.C., 1956, pp. 58-169.

4. Rowe, P.W., "Large Scale Laboratory Model Retaining Wall Appratus," Proceedings of Roscoe Memorial Symposium, Cambridge, England, 1971, pp. 279-289.

5. James, R.G., and Larsen, H., "Centrifugal Model Tests of Buried Rigid Pipes," Proceedings of the Ninth International Conference on Soil Mechanics and Foundation Engineering, Tokyo, Japan, 1977.

6. Katona, M.G., Smith, J.M., Odello, R.J., and Allgood, J.R., "CANDE - A Modern Approach for the Structural Design and Analysis of Buried Culverts," Report No. FHWA/RD-77/5, Federal Highway Administration, Washington, D.C., October, 1976.

7. Katona, M.G., Vittes, P.D., Lee, C.H., and Ho. H.T., "CANDE-1980: Box Culverts and Soil Models," Report No. FHWA/RD-80/172, Federal Highway Administration, Washington, D.C., May, 1981.

8. Lambe, T.W., and Whitman, R.V., Soil Mechanics, John Wiley and Sons, Inc., New York, N.Y., 1969.

9. Duncan, J.M., et al., "Strength, Stress-Strain and Bulk Modulus Parameters for Finite Element Analyses of Stresses and Movements in Soil Masses," Report No. UCB/GT/78-02, National Science Foundation, April, 1978.

10. Kim, Y.S., and Davis, R.E., "Proof Testing of a Structural Plate Pipe with Varying Bedding and Backfill Parameters Section VII, Volume 3: Finite Element Analysis," Report No. FHWA/CA/SD-83/04, California Department of Transportation, Sacramento, California, August, 1983.

11. Leonards, G.A., Wu, Tzong-Hsin, and Juang Charng-Hsein, "Predicting Performance of Buried Conduits," Report No. FHWA/IN/JHRP-81/3, Indiana State Highway Commission, Indianapolis, Indiana, June, 1982.

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